Effects of Fiber Finish on Mechanical, Low and High Speed Impact of Glass Fiber Reinforced Composites

Ramakrishna Iyer[*], Timothy Woo[§], John Osterndorf[§] and Dan Prillaman[§]

[*]: US Army, RDECOM - TARDEC, Warren, MI 48397
[§]: US Army, RDECOM - ARDEC, Picatinny, NJ 07801

Matthew Dabrowski[§], Bill Chen[£], Yong Lei[£] and Jerry Chung[§]

[§]: Novus Technologies Corporation, NY, NY, 10031
[£]: Frontier Performance Polymers Corporation, Dover, NJ 07801

Feridun Delale and Benjamin Liaw

The City College of New York, NY, NY, 10031

" UNCLASSIFIED: Dist A. Approved for public release

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **12 MAY 2011**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Effects of Fiber Finish on Mechanical, Low and High speed Impact of Glass Fiber Reinforced Composites**	5a. CONTRACT NUMBER **W56HZV-09-C-0569**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **R. Iyer; T. Woo; J. Osterndorf; D. Prillaman M. Dabrowski; B. Chen; Y. Lei; J. Chung; F. Delale; B. Liaw**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army, RDECOM-TARDEC, Warren, MI 48307 US Army. RDECOM-ARDEC, Picatinny, NJ 07801 Novus Technologies Corp. NY, NY 10031 Frontier Performance Polymers Corporation, Dover, NJ 07801 The City College of New York, NY, NY 10031**	8. PERFORMING ORGANIZATION REPORT NUMBER **21823**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA**	10. SPONSOR/MONITOR'S ACRONYM(S) **TACOM/TARDEC/RDECOM**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **21823**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**35**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Polymer Matrix Composites

- Large Variety In Material Type And Cost
  - Matrix: type, cost, properties
  - Reinforcement: shape, material, cost

- Promising Advantages
  - Much lower density than metals
  - Excellent specific strength and stiffness to weight ratio
  - High damping & fatigue endurance
  - Low thermal coefficient
  - Good corrosion resistance
- Potential Application For Lightweight Energy Absorbing Materials

PMC Impact Performance

- Mechanisms For Dissipating Energy

Delamination

Plug punch-out

Resin matrix cracking

Fiber pull-out

Fiber fracture

Interfacial Adhesion Between Matrix & Reinforcement

Impact Performance

Structural Integrity

Adjustable Interfacial Adhesion

- Matrix
  - Mechanical Properties
  - Chemical Properties
  - Physical Properties
- Reinforcing Fiber
  - Types of Fiber
  - Thickness/count
  - Weave type
  - Finish/sizing

Interfacial Adhesion

Significance Of This Research

- Investigate The Effects Of Four Glass Fiber Finishes On Mechanical Properties And Low/High Speed Impact Performance
  - Greige
  - Heat-burnt
  - Volan
  - Silane
- Correlate The High Speed Impact Properties With Mechanical Properties
- Correlate The High Speed Impact Properties With The Interfacial Adhesion (To be done in the near future)

Part 1

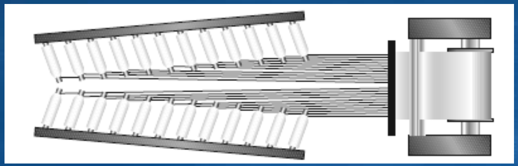
Experimental Procedures

Materials

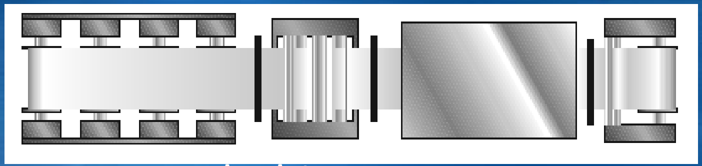
- Matrix Resins
  - Polypropylene Film
  - Polyester resin system
    - 98.5 wt% Aropol® 7241T-15 (46% styrene)/1.5wt% Methyl ethyl ketone peroxide (MEKP)
  - Vinyl Ester
    - 98.12wt% Derakane 411-350/1.5wt% MEKP/0.03wt% 2,4-Pentanedione/0.05wt% dimethylamine/0.3wt% cobalt naphthenate
- Glass Fiber: Hexcel® 1581 Series Glass Fiber Fabrics

Fabric	Finish	Weave	Weight	Thickness
1581-F12	None (Heat-burnt HB)	8H Satin	298 g/m^2	2.16x10^{-4} m
1581- GR	Greige	8H Satin	298 g/m^2	2.16x10^{-4} m
1581-F16	Volan	8H Satin	298 g/m^2	2.16x10^{-4} m
1581-F69	Silane	8H Satin	298 g/m^2	2.16x10^{-4} m

Glass Fabric Fabrication Process

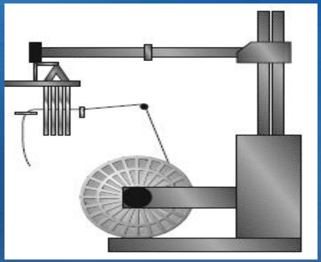


Warping

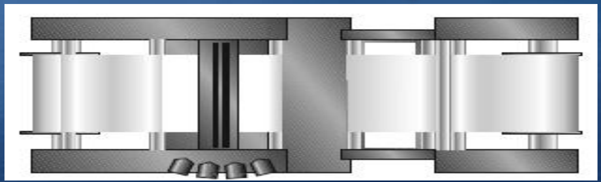


Slashing

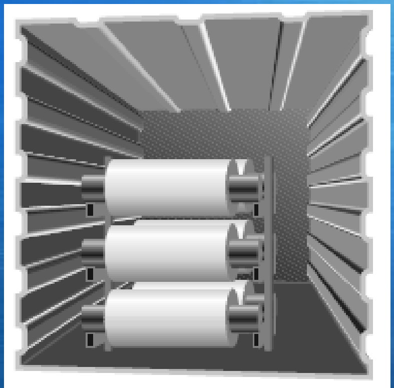
Entering



Weaving

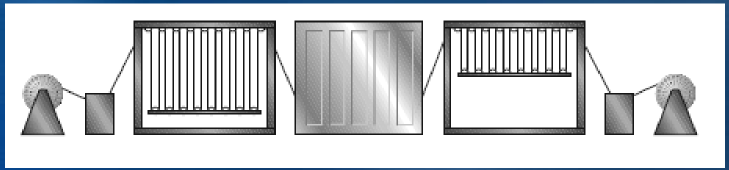


1581- GR



Heating

1581- F12



Finishing

1581- F16
(Volan)

1581- F69
(Silane)

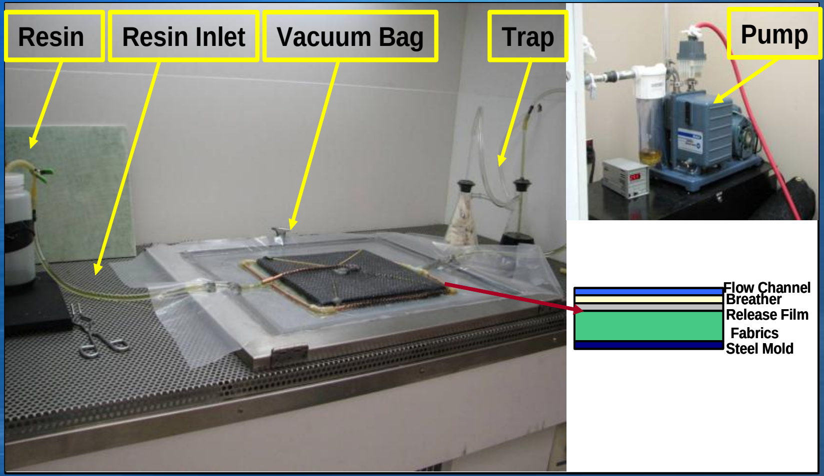
Compression Molding

For Fabricating PP Composite Specimens

- Vacuum Hot Press
  - Evenly Distribute And Lay Up Fabric Sheets And PP Film Based On The Requirements Of The Thickness And Fiber Content
  - Put Closed Mold Into Compression Press
  - Compression Mold At 235°C Under 1.5 MPa For 70 Min
  - Cool Down And De-mold

Vacuum Infusion

For Producing Polyester Or Vinyl Ester Composite Specimens



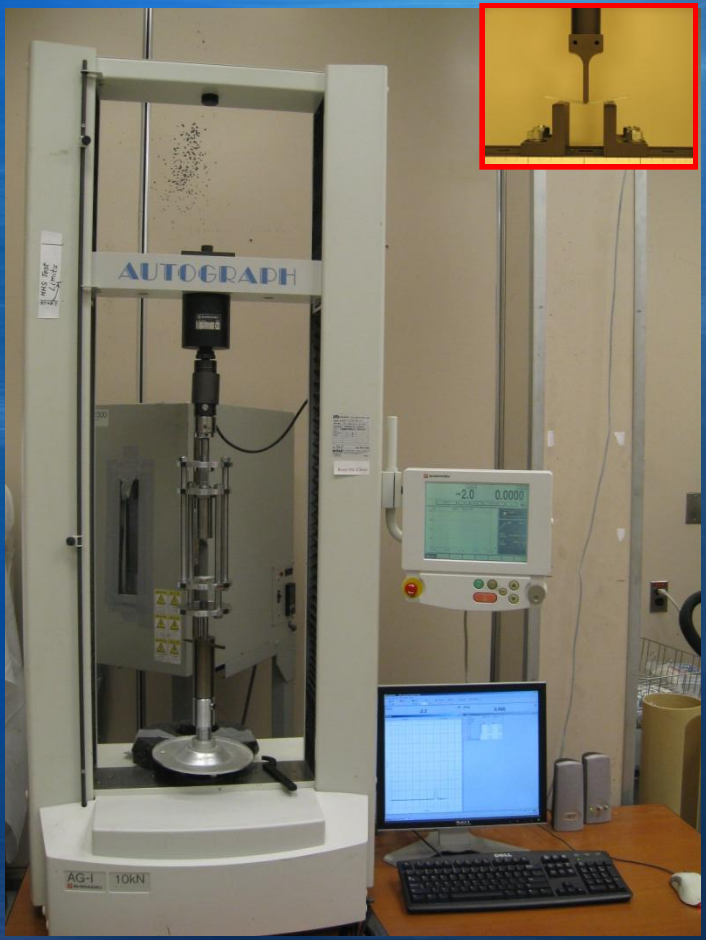
- Process
  - Lay down glass fiber, peel ply, and flow channel
  - Place vacuum conduit around mold, hook conduit end to vacuum pump
  - Seal the set-up and resin inlet
  - Turn on pump (achieve >1 torr vacuum)
  - Formulate resin and connect resin inlet to resin mixture
  - Start resin infusion
  - Stop the pump when the infusion is completed

Tensile Property Testing

- Universal Tensile Tester
  - 200KN Capacity
- Standard
  - ASTM D3039

Flexural Property Testing

- Universal Tensile Tester
  - 10KN Capacity
- Standard
  - ASTM D790



Low Speed Impact Testing

- Sample: ¼” panels
- Instrumented Impact Tester
  - Speed up to 10 ft/s
- Standard
  - ASTM D3763
- Tup
  - A custom designed impact tup

High Speed Impact Testing

- Sample: ⅛" panels
- Standard
  - Mil-STD-662F
- High Speed Impact Projectiles As Per Mil-STD-662F
- Data Collection
  - Velocity (V_{50}) and Impact Energy at 50% probability of penetration
  - Impact Energy Absorption

Part 2

Experimental Results

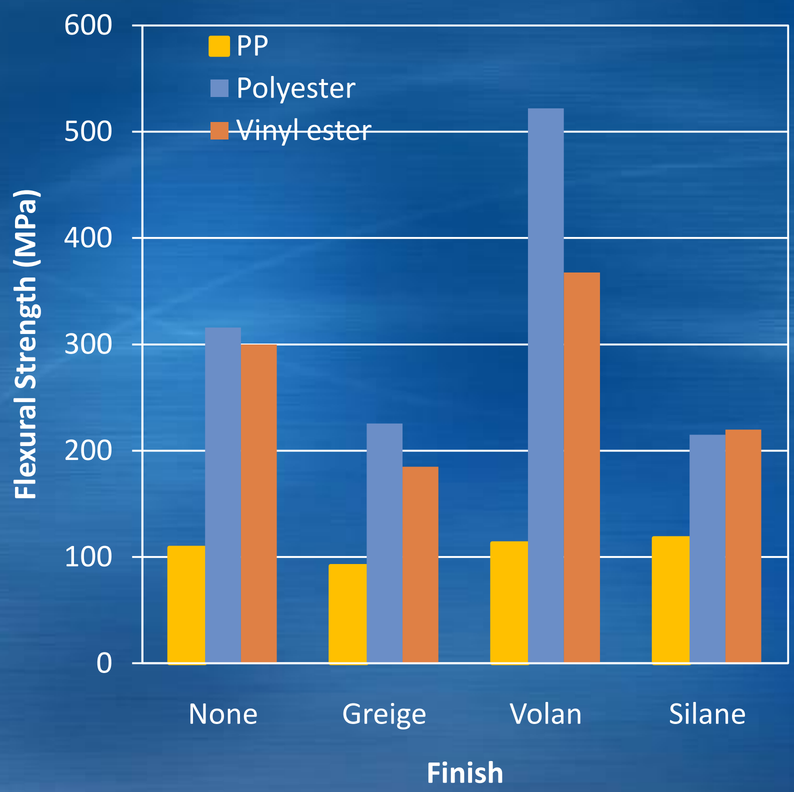
Areal Density And Fiber Content

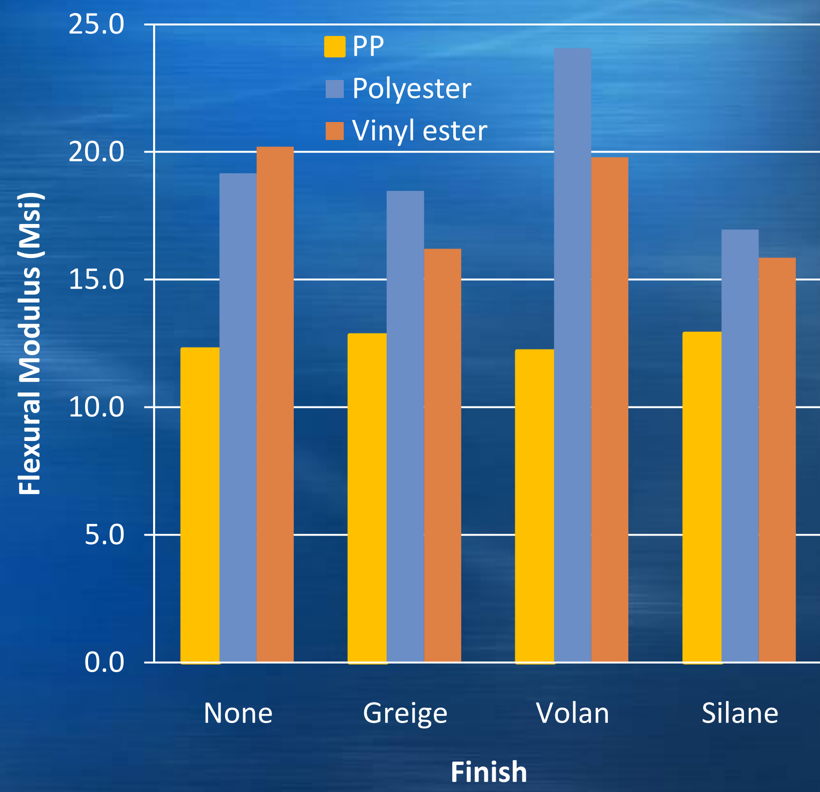
3.2mm Thick Composite Specimens

Reinforcement	Finish	Matrix	Fiber Content (%)
Hexcel 1581-F12	Heat Burnt (No Finish)	PP	71.0
		Polyester	70.0
		Vinyl ester	66.2
Hexcel 1581-GR	Greige (Starch and Oils)	PP	67.0
		Polyester	65.6
		Vinyl ester	71.2
Hexcel 1581-F16	Volan	PP	64.0
		Polyester	69.0
		Vinyl ester	65.2
Hexcel 1581-F69	Silane	PP	70.0
		Polyester	64.7
		Vinyl ester	66.2

Flexural Strength And Modulus

Effects of Matrix Resins And Glass Surface Finishes

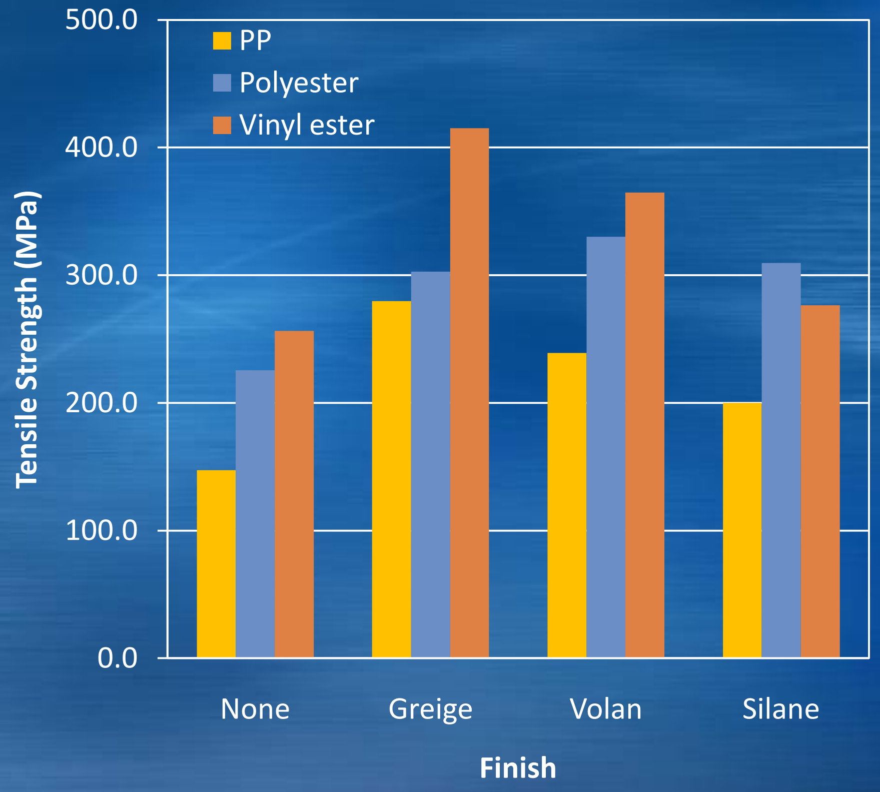


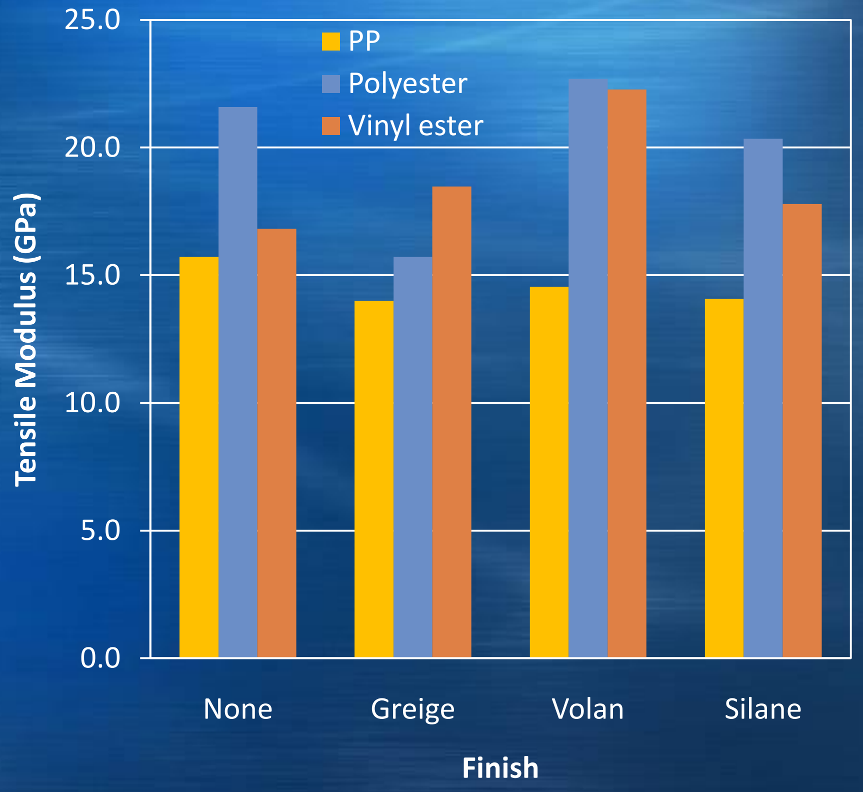


- PP Has Significantly Lower Flexural Properties
- Volan Finish Has Highest Flexural Properties

Tensile Strength And Modulus

Effects of Matrix Resins And Glass Surface Finishes

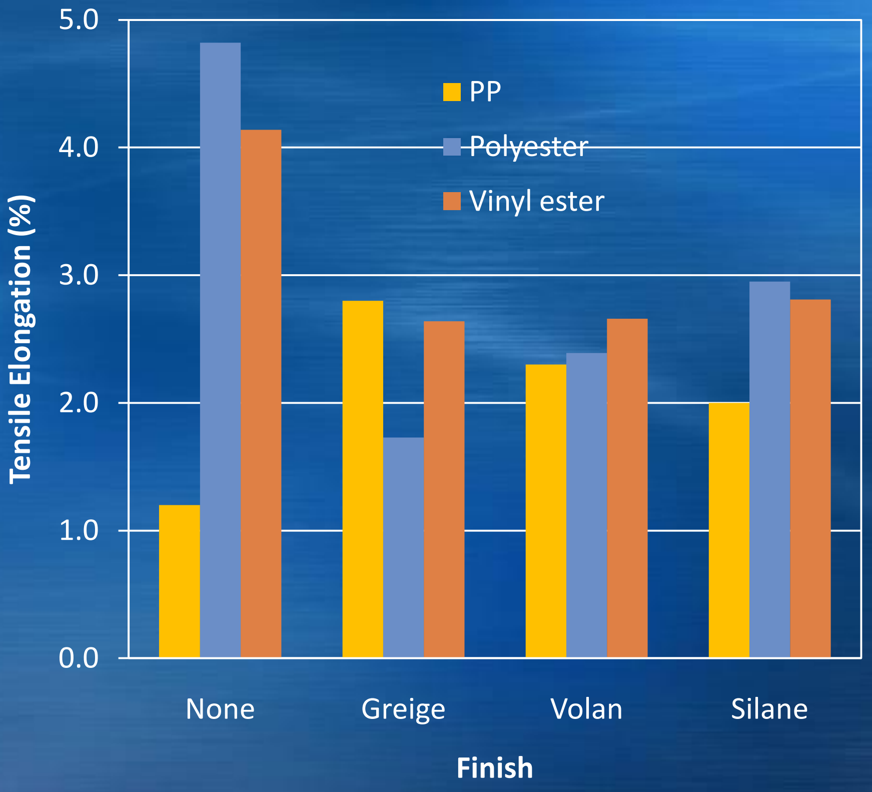




- PP Has Slightly Lower Tensile Strength and Modulus
- Volan Finish Has Better Overall Tensile Properties

Tensile Elongation

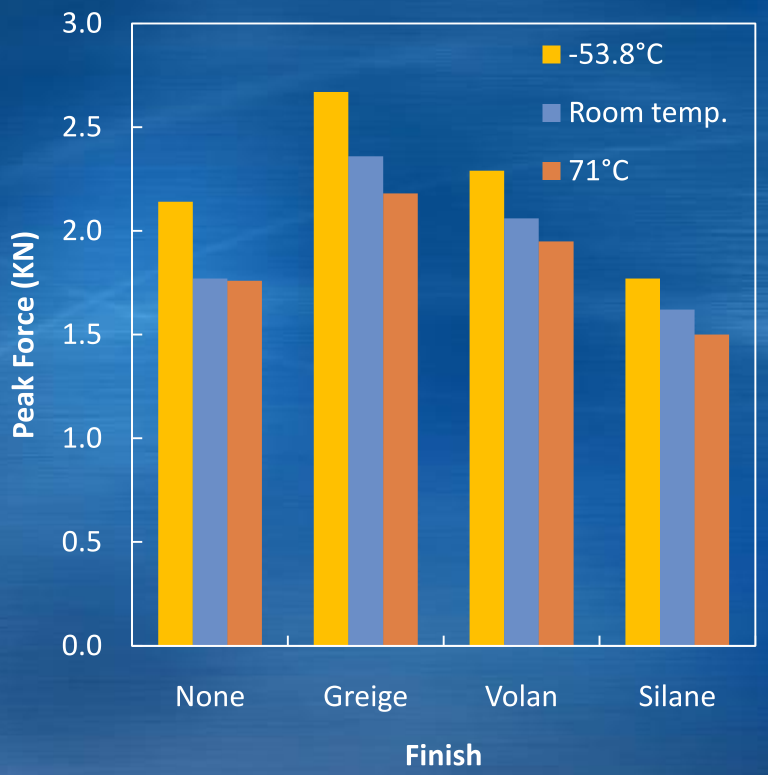
Effects of Matrix Resins And Glass Surface Finishes

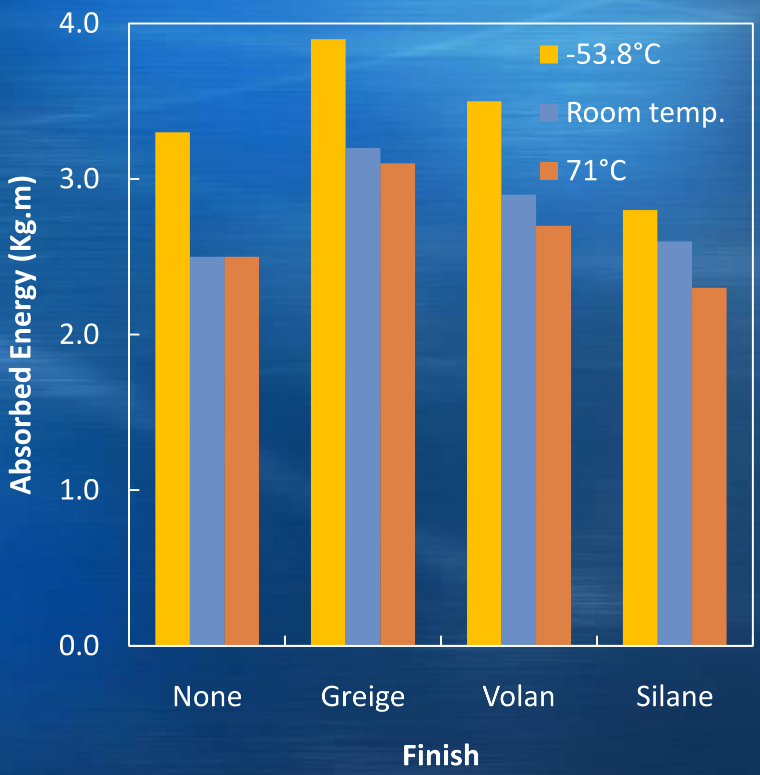


- Heat Burnt Finish Has Highest Tensile Elongation

Low Speed Impact Performance

Effects of Temperatures On PP Composites

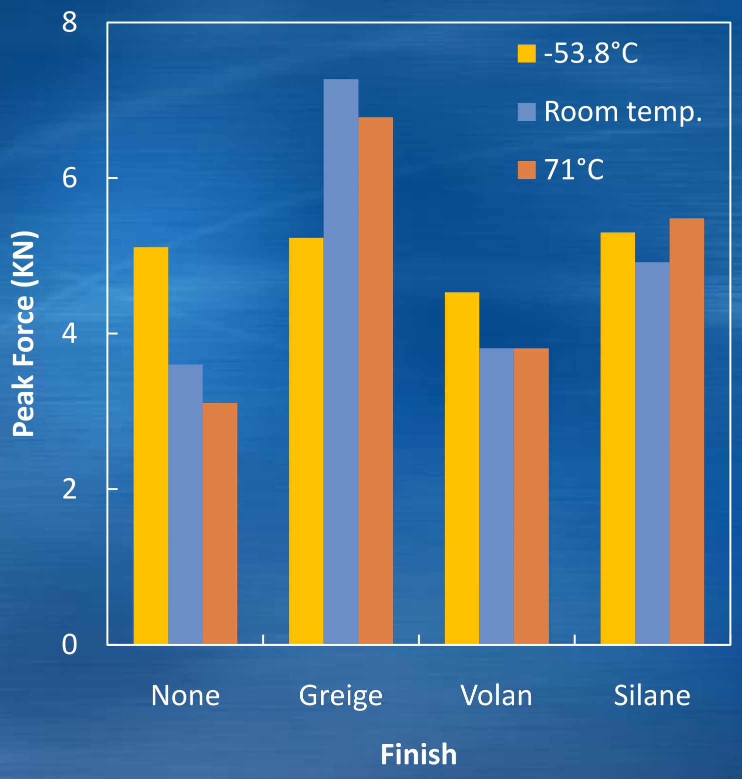


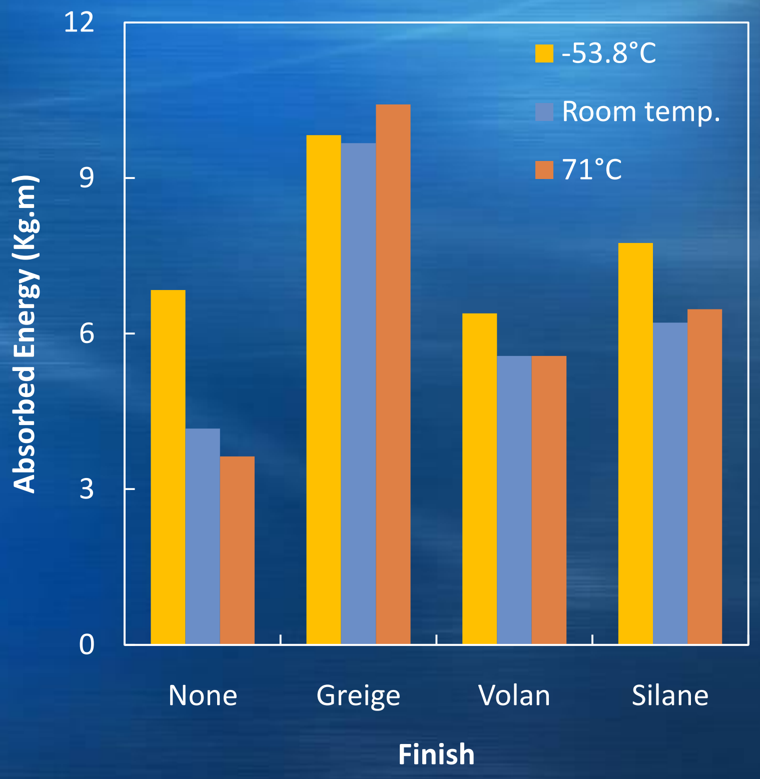


- Greige Finish Has Best Low-Speed Impact Performance
- Impact Performance Decreases With Increase In Temperature

Low Speed Impact Performance

Effects of Temperatures On Polyester Composites

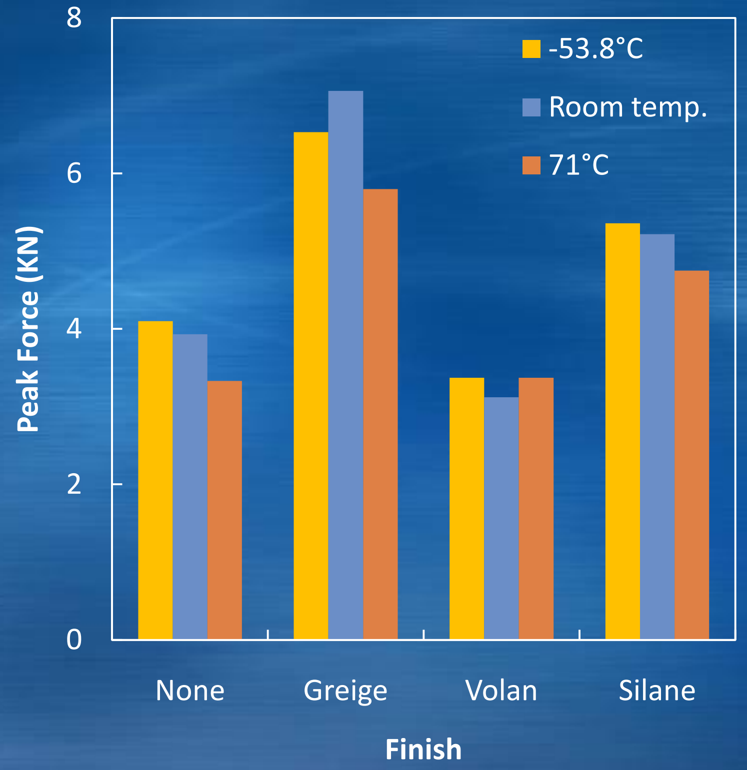


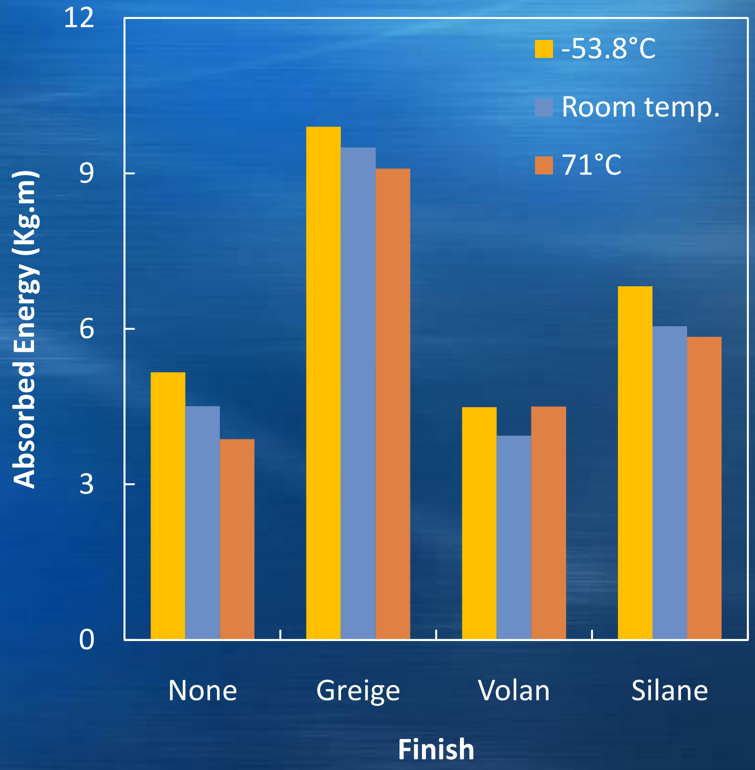


- Greige Finish Has Best Low Speed Impact Performance

Low Speed Impact Performance

Effects of Temperatures On Vinyl Ester Composites

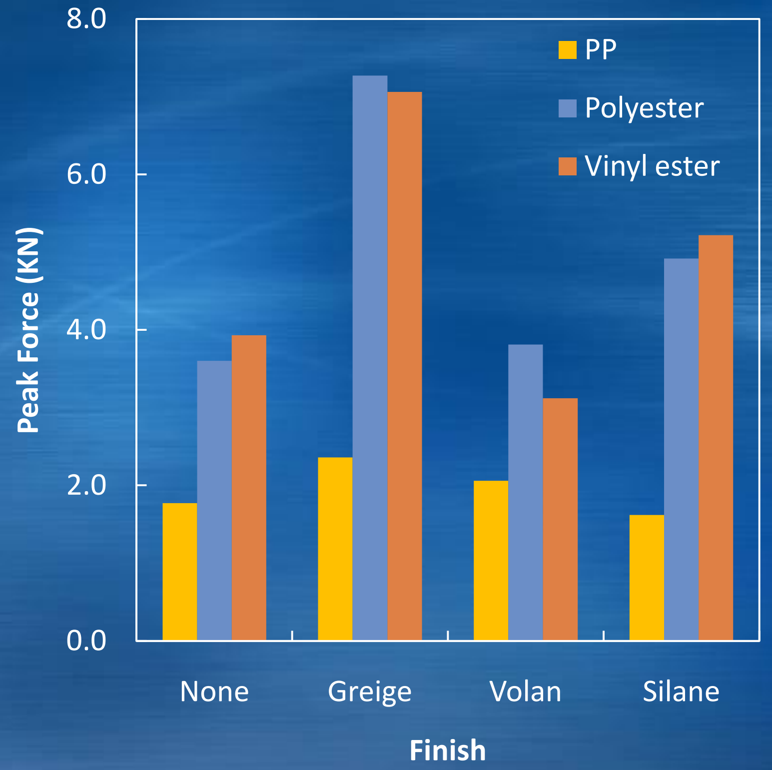


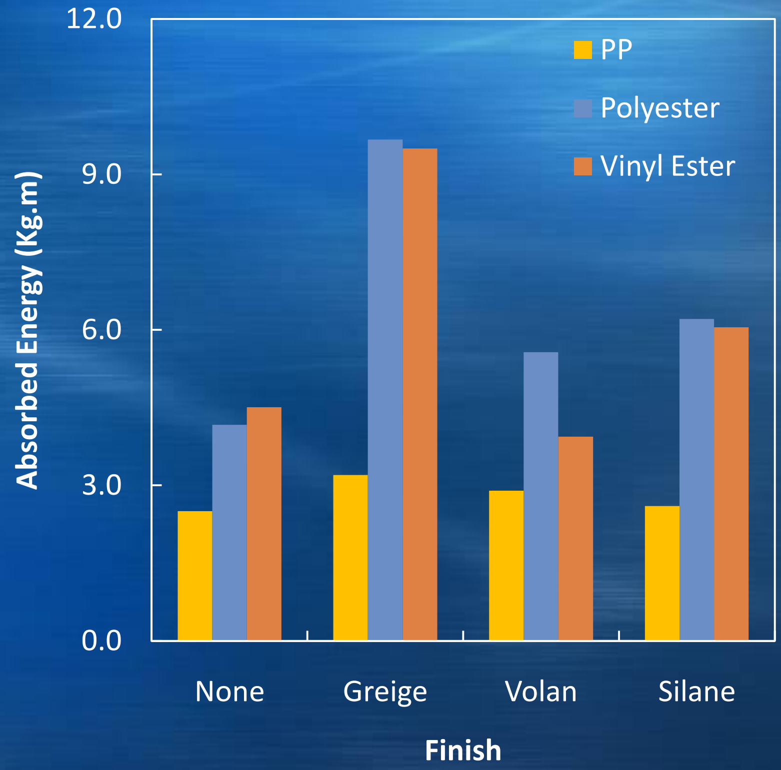


- Greige Finish has Best Low Speed Impact Performance

Effects Of Resins And Fiber Finishes

Low Speed Impact Performance At Ambient

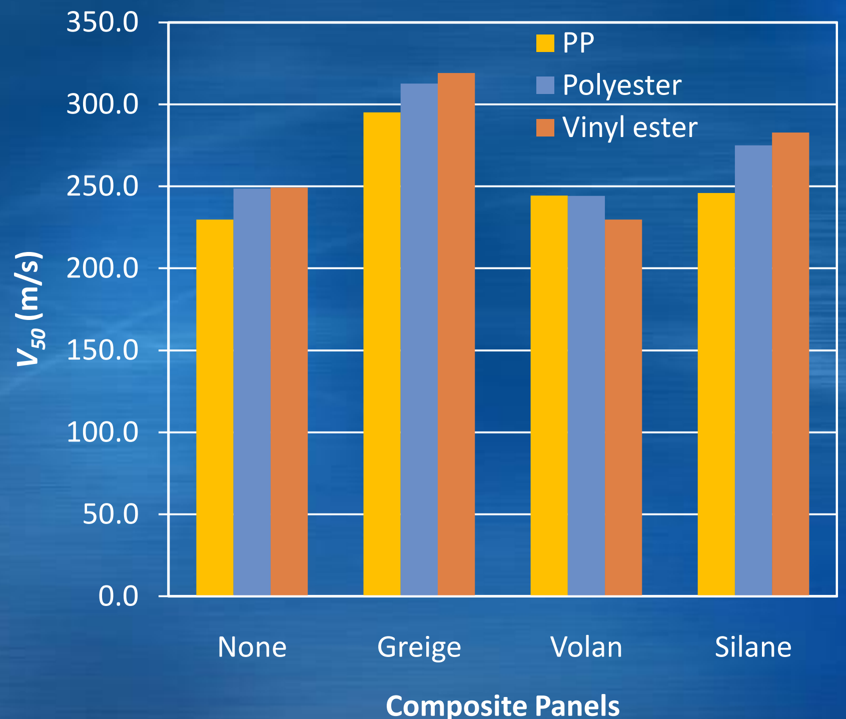


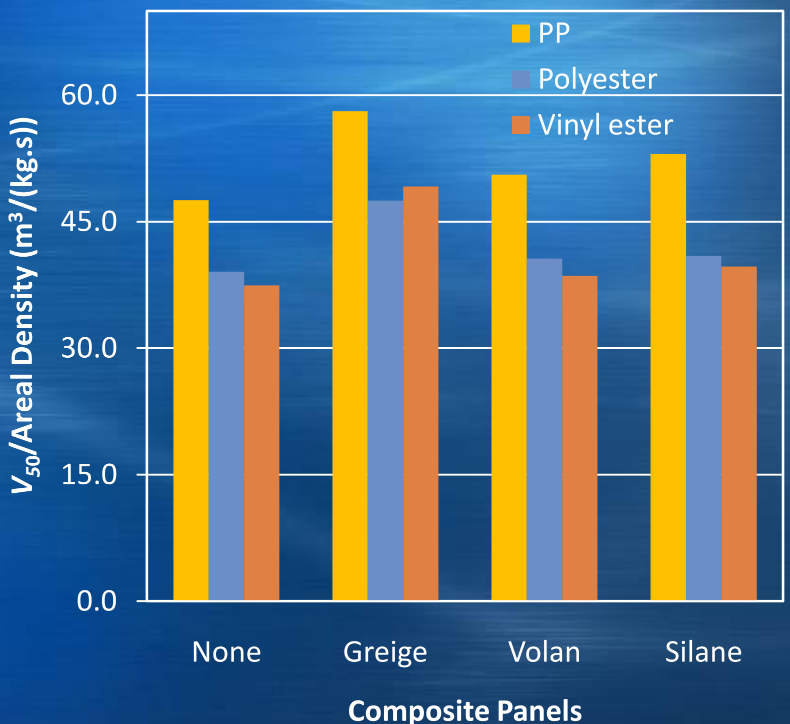


- Greige Finish: Highest Low Speed Impact Performance

High Speed Impact Performance

V_{50} And V_{50}/Areal Density for 3.2mm Samples

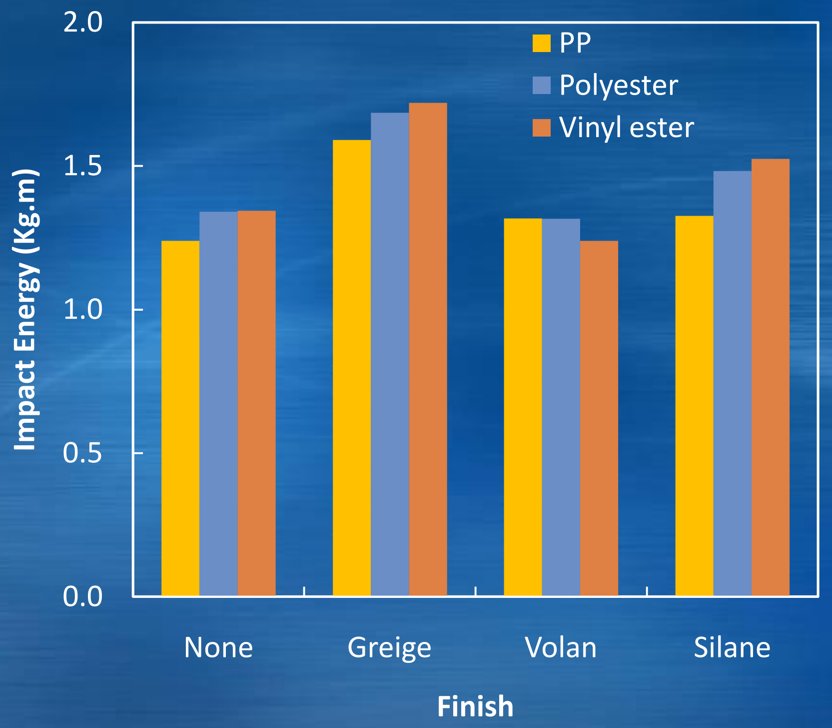


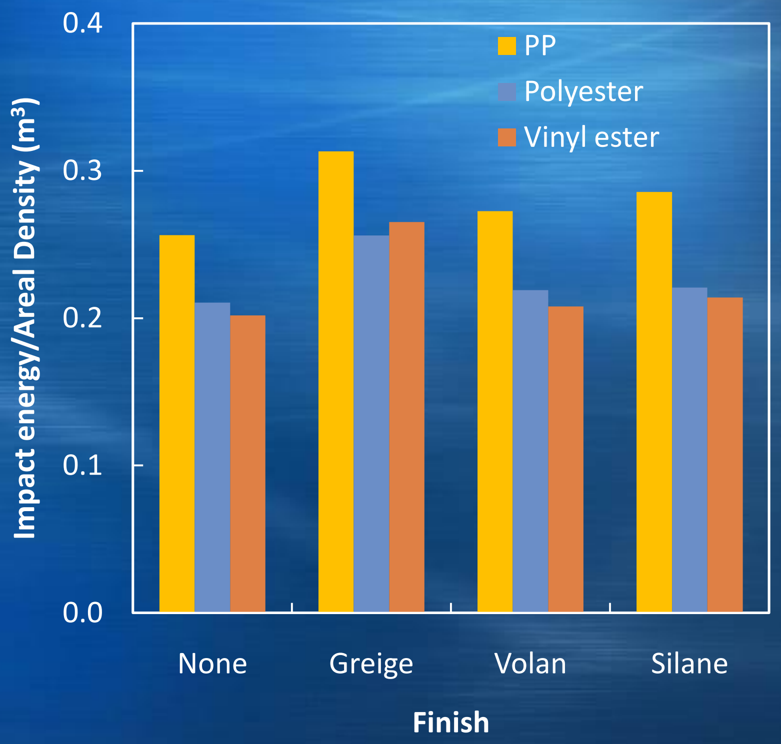


- Greige Finish Has Highest High Speed Impact Performance
- PP Composite Has Highest High-Speed Impact Efficient

High Speed Impact Performance

Impact Energy And Impact Energy Per Areal Density for 3.2mm Samples

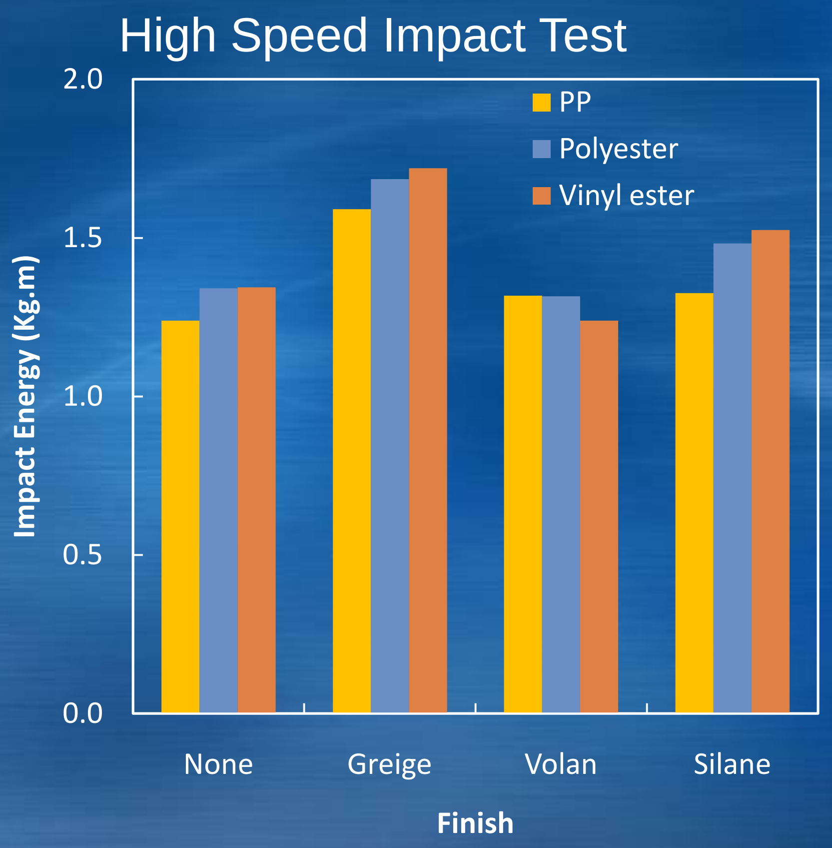


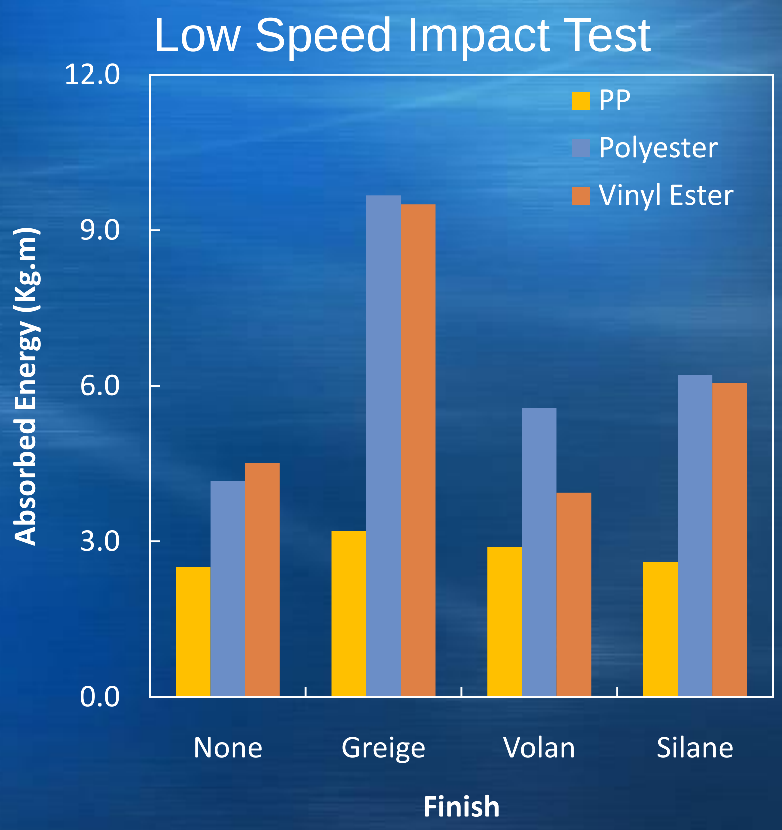


- Greige Finish Has Highest High Speed Impact Performance
- PP Composite Has Highest High-Speed Impact Efficient

High Vs. Low Speed Impact

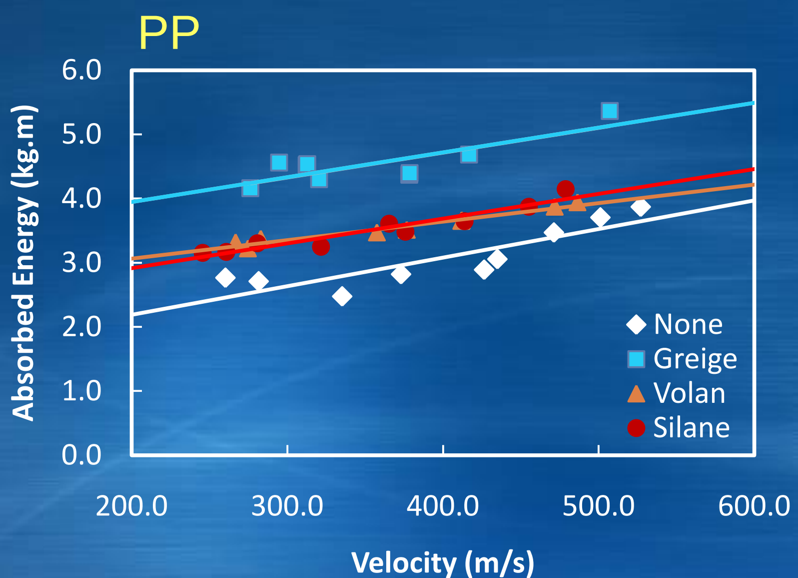
Impact Energy Comparison at Ambient for 3.2mm Samples

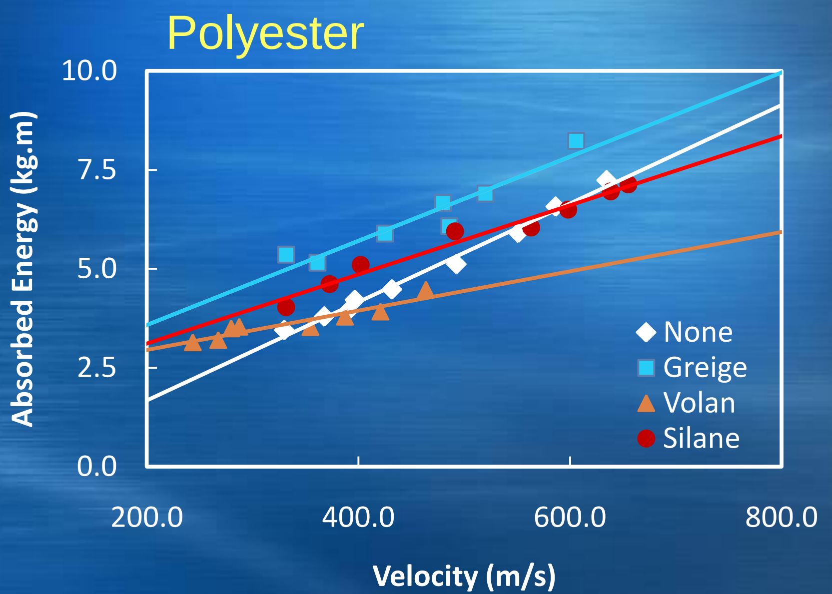




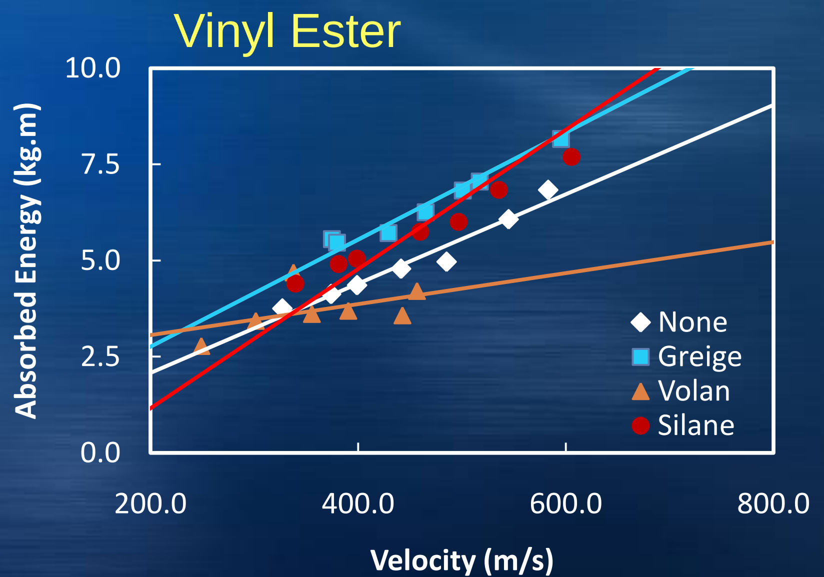
- Results From Low Speed Impact Can Not Predict High Speed Impact Performance Between Different Resin Systems

Impact Energy Absorption

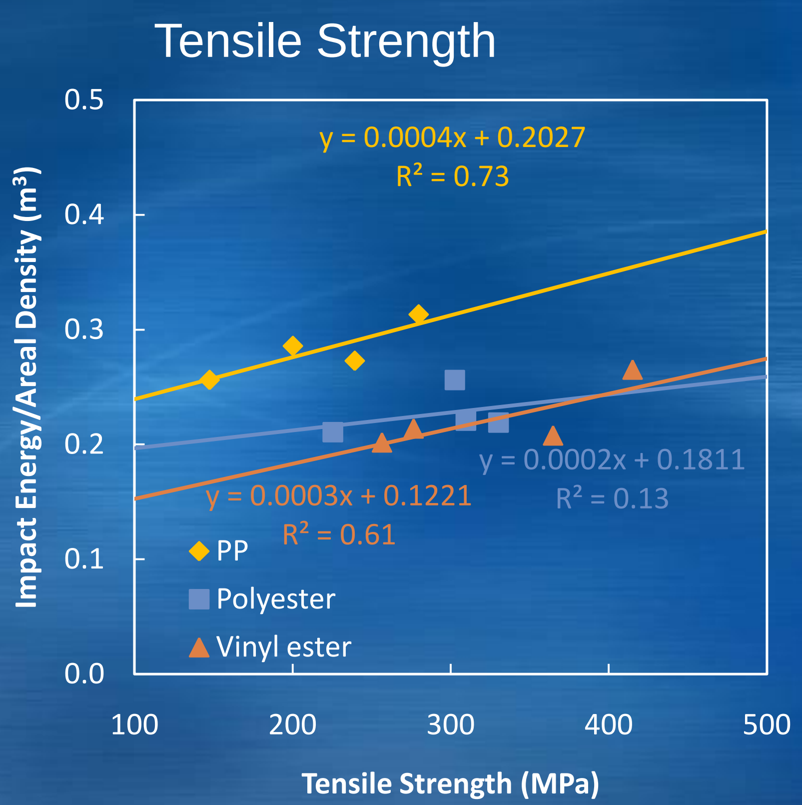


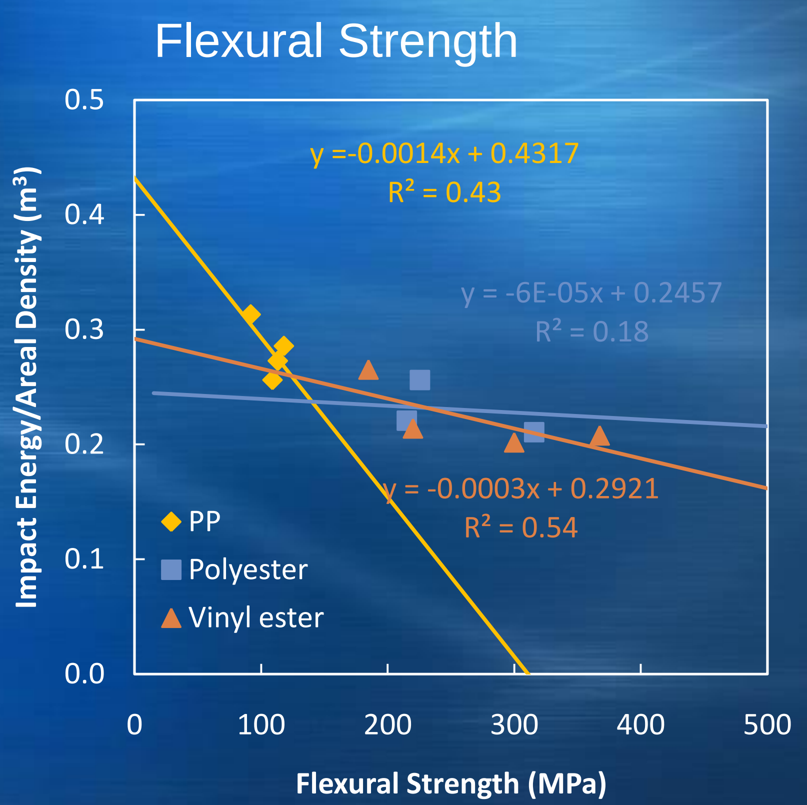


- Impact Energy Absorption Increases With Projectile Velocity
- Greige Finish Has Higher Impact Energy Absorption
- PP Resin Has Lower Impact Energy Absorption



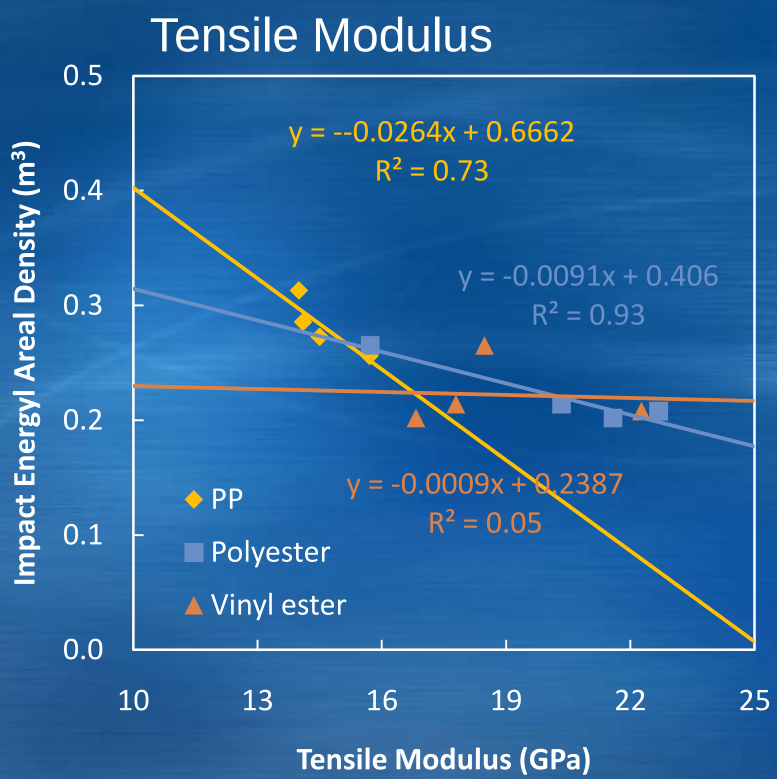
Impact Energy Vs. Strength

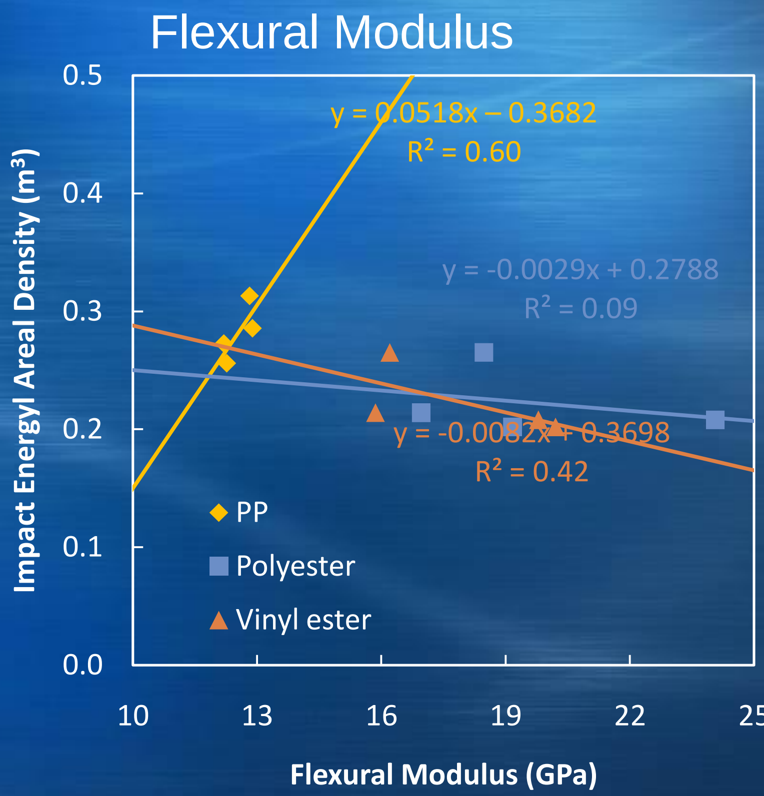




- Impact Energy Is Nearly Proportional To Tensile Strength

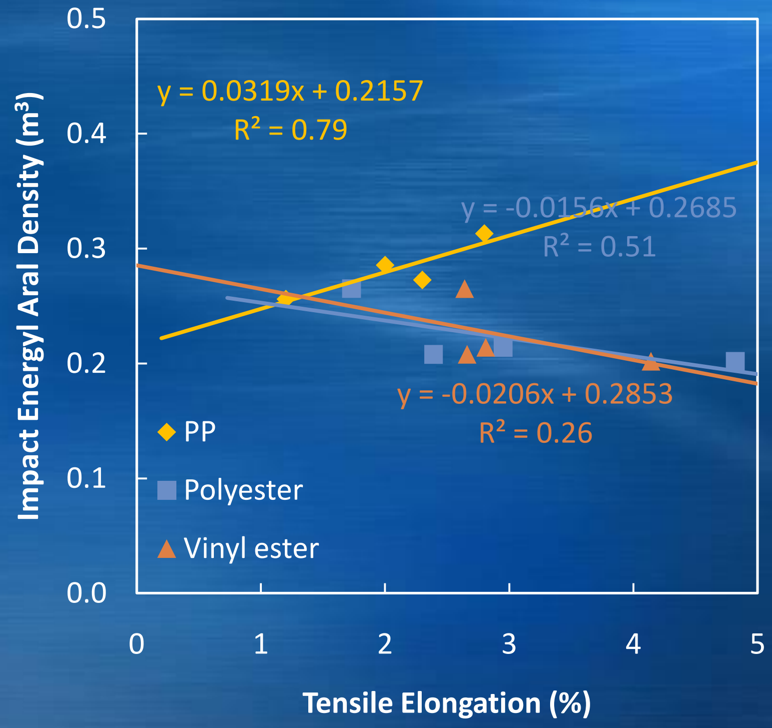
Impact Energy Vs. Modulus





- No Obvious Correlation With Tensile Or Flexural Modulus

Impact Energy Vs. Elongation



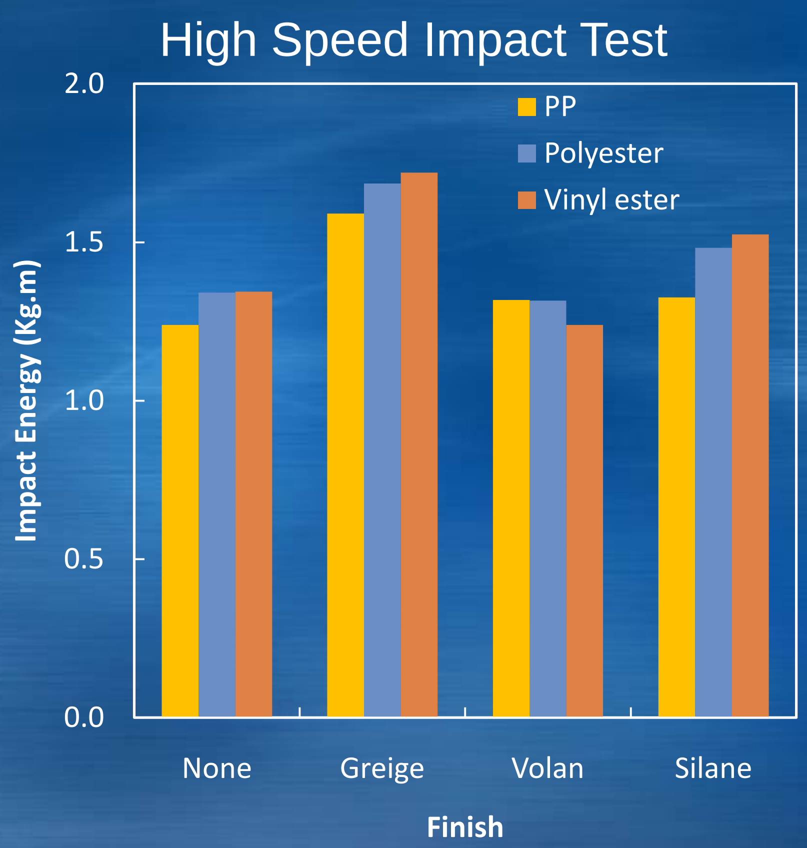
- No Obvious Correlation Observed

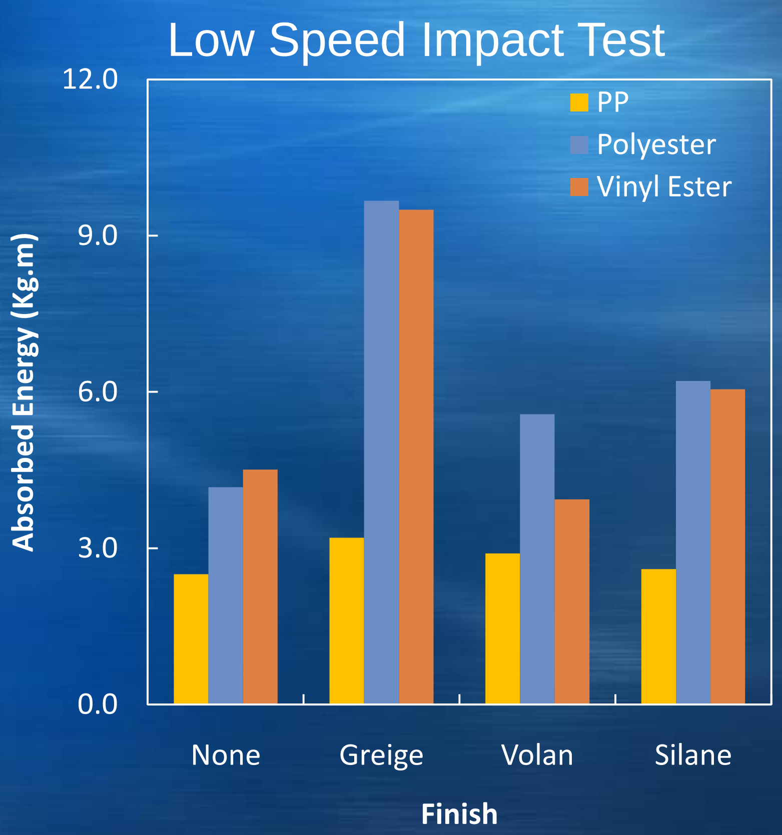
Part 3

Conclusion

High Vs. Low Speed Impact

Impact Energy Comparison at Ambient





- Results From Low Speed Impact Can Not Predict High Speed Impact Performance Between Different Resin Systems

Summary And Conclusion

- Surface Finish On Glass Fiber Fabrics Affects Mechanical Properties As Well As Impact Performance Of Resulted Composites
- GR Finish Results In Higher Impact Resistance
- Despite its Low Mechanical Properties, PP Composite Has Better Impact Resistance
- Tensile Strength May Be A Critical Factor For Attaining High Impact Resistance

Acknowledgements

- **RDECOM-TARDEC:** US Army's Tank Automotive Research, Development & Engineering Center
  - Contract Number: W56HZV-09-C-0569
- **RDECOM-ARDEC:** US Army's Armament Research, Development & Engineering Center
  - Contract Number: W15QKN-08-C-0533

THANK YOU

Any Questions?